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6 MODIFICATION TYPE: NEW

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10 PROPOSAL DATE: 01/23/2015

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13. ISSUED TO
13a. ADDRESS:
WOODS HOLE OCEANOGRAPHIC INSTITUTIO
266 WOODS HOLE RD
WOODS HOLE MA 02543-1536
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13c EDI/EFT NUMBER: N/A

14 REMITTANCE ADDRESS (IF DIFFERENT FROM BLOCK 13):
Same as Block # 13

13d. BUSINESS OFFICE CONTACT: David Stephens

13e. TELEPHONE NUMBER: 5082893542

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15 RESEARCH TITLE AND/OR DESCRIPTION OF PROJECT AND/OR PROPOSAL TITLE.
Upper-Ocean Variability in the Arctic's Amundsen and Nansen Basins

16. FUNDING	ACTIVITY/AGENCY SHARE	RECIPIENT SHARE	TOTAL
PREVIOUSLY OBLIGATED:			$0.00
OBLIGATED BY THIS ACTION:			$149,049.00
TOTAL OBLIGATED ON AWARD:			$149,049.00
FUTURE FUNDING:			$159,188.00
GRANT TOTAL			$308,237.00

17. CURRENT FUNDING PERIOD: N/A THROUGH N/A

18. PERIOD OF PERFORMANCE: 04/30/2015 THROUGH 02/28/2017

19 ACCOUNTING AND APPROPRIATION DATA
See Attached Financial Accounting Data Sheet(s)

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25a PAYING OFFICE:
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26b. CODE: N00014

AWARD NO. N00014-15-1-2547	AWARD/MODIFICATION	MODIFICATION NO.	

27. SPECIAL INSTRUCTIONS:
See Special Requirements on Page 5

28. DELEGATIONS: The administration duties listed below have been delegated to the administrative office (block 23a). Upon request the awarding office contact (block 22) will make their full text available. Please direct questions to the contacts @ http://www.onr.navy.mil/Contracts Grants/Regional-Contacts.aspx

Full Delegation

29. TERMS AND CONDITIONS. The following terms and conditions are incorporated herein by reference with the same force and effect as if they were given in full text. Upon request the awarding office contact named in block 22 will make their full text available, or they can be found at the specified URL.

DOCUMENT	URL

The following documents may be found at :
http://www.onr.navy.mil/Contracts-Grants/submit-proposal/grants-proposal/grants-terms-conditions.aspx
STANDARD TERMS/CONDITIONS FOR RESEARCH GRANTS (CORE) (JUNE 2011)
UAAC ACCEPTANCE C (NOV 2003)
UAWA AWARD A (NOV 2003)
STANDARD TERMS/CONDITIONS FOR RESEARCH GRANTS (AGENCY SPECIFIC) (FEB 2015)
SPECIAL TERMS AND CONDITIONS (POLICY FOR IN SITU OCEAN DATA ARTICLE) (OCT 1999)

30. OPTIONS	OPTION NO.	AMOUNT	PERIOD
(1)			
(2)			
(3)			
(4)			

31. REPORTS: The following reports must be submitted to the indicated addressees, in the indicated quantities, within 90 days following the expiration or termination of the project. Final Technical Reports must have a SF298, Report Documentation Page, accompanying them. Unless otherwise stated in the award/modification, complete Block 12a of the SF298 as follows: "Approved for Public Release, distribution is Unlimited".

ADDRESSEE	REPORT TYPE	COPIES
See block #21	Final Technical Report with SF298 Performance /Technical Report (As Required) with SF298	1 1
See block #23a	Report of Inventions and Subcontracts - DD 882 Final Technical Report transmittal Letter only Performance /Technical Report - As Required) Final Federal Financial Status Report - SF425 - Including Line Item 11	1 1 1 1
Defense Technical Information Center 8725 John J Kingman Road Ste 0944 Fort Belvoir, VA 22060 6218	Final Technical Report with SF298 Performance Technical Report (As Required) with SF298	1 1
See block #26a	Report of Inventions and Subcontracts - DD 882 Final Technical Report	1 1
Naval Research Laboratory ATTN: CODE 5596 4555 Overlook Avenue SW Washington, DC 20375-5320	Final Technical Report Performance Technical Report - As Required) with SF298	1 1

32. FOR THE RECIPIENT		33. FOR THE UNITED STATES OF AMERICA	
32a. SIGNATURE OF PERSON AUTHORIZED TO SIGN		33a. SIGNATURE OF AWARDING OFFICER /S/ ELIZABETH FORD	
32b. NAME AND TITLE OF SIGNER	32c. DATE SIGNED	33b. NAME AND TITLE OF AWARD OFFICER ELIZABETH FORD	33c. DATE SIGNED 07/21/2015

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Upper-Ocean Variability in the Arctic's Amundsen and Nansen Basins

5a. CONTRACT NUMBER

5b. GRANT NUMBER
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5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
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Cole, Sylvia T.

5d. PROJECT NUMBER
WHOI 132547SP

5e. TASK NUMBER

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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12. DISTRIBUTION/AVAILABILITY STATEMENT
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13. SUPPLEMENTARY NOTES

14. ABSTRACT

This grant funded the deployment of an Ice-Tethered Profiler with Velocity (ITP-V) instrument during the summer 2015 Nansen and Amundsen Basins Observational System cruise and analysis of data. The observations explore upper ocean variability and ice-ocean interaction in the Arctic's Amundsen and Nansen Basins as a complement to those made in the Canada Basin during the Marginal Ice Zone DRI program of 2014. The fieldwork leveraged other ITP deployments supported by the NSF Arctic Observing Network program. Analysis of the recovered data extend the findings of the MIZ program to the European sector of the Arctic with its markedly different thermohaline stratification.

15. SUBJECT TERMS
Arctic Ocean
Air-Ice-Ocean Interaction

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			John M. Toole
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Upper-Ocean Variability in the Arctic's Amundsen and Nansen Basins

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http://www.whoi.edu/itp; http://www.whoi.edu/page.do?pid=147016

1. Long Term Goals

The PI group seeks to build understanding of the physical processes controlling the Arctic's evolving air-ice-ocean system in support of efforts to predict its future state. A secondary goal is to develop and perfect autonomous instrument systems to observe the upper Arctic Ocean.

2. Objectives

The objectives of this project were to collect and analyze exploratory observations of upper-Arctic-Ocean velocity and thermohaline stratification variations in the Eurasian sector of the Arctic. The results constitute a comparison/contrast with previous observations and findings from the Marginal Ice Zone DRI program that took place in the Canada Basin.

3. Approach

Observations were collected using an Ice-Tethered Profiler with Velocity (ITP-V), Figure 1. The ITP system consists of a surface buoy that sits atop a polar ice floe (or floats in open water) supporting a wire-rope tether extending down to ~800 m depth and a vehicle that propels itself up and down the tether carrying sensors that measure the sea water properties. Sensor data collected by the underwater unit are periodically communicated to the surface buoy that in turn relays them to shore via satellite. The ITP-V variant, configured with a conductivity-temperature-depth (CTD) sensor and 3-axis current meter, is now an operational instrument system, as demonstrated by its successful use in the Marginal Ice Zone DRI program. The ITP-V may be programmed to collect vertical profiles of ocean temperature, salinity and horizontal velocity at few-hour interval as well as sample for specified time periods while the vehicle holds a specified depth. Data from the latter observational periods may be used to estimate vertical turbulent fluxes of heat, salt and momentum.

4. Tasks Completed

One of the ITP-V instrument systems deployed for the MIZ study was recovered, refurbished, recertified and redeployed in the Eurasian Arctic from the Russian icebreaker *Akademik Tryoshnikov* in conjunction with the Nansen and Amundsen Basin Observing System program (NABOS) on September 13, 2015 at 80.6765°N, 166.4581°E. The ITP-V was deployed together with an NPS Autonomous Ocean Flux Buoy - http://www.oc.nps.edu/~stanton/fluxbuoy/ and two Bigelow Laboratory O-Buoys - http://www.o-buoy.org/. ITP-V #92 was programmed to sample like the ITP-V systems deployed for the MIZ program - specifically, vertical temperature, salinity and velocity profiles were collected every 3 hours in the upper 250 m of the water column, with two of these one-way profiles extending to 750 m depth every other day. In addition, 20-minute time series were collected just below the ice-ocean interface several times per day to support direct covariance flux estimates of the turbulent vertical heat, salt and momentum fluxes.

The ITP-V system drifted north and east after deployment, Figure 2, operating normally until February 22, 2016 when communications from the instrument ceased. We believe the system was enveloped by an ice ridging event and buried. It is possible that the system will reemerge at a later date and transmit data that were acquired and stored internally while the system was under the ice. There are no guarantees this will happen. The data acquired up to 2/22/16 have been processed and estimates of the absolute ocean velocity, and turbulent exchanges between the sea ice and upper ocean are in hand. The processed data from the instrument are being used to investigate ice-ocean interactions and seasonal variability of the upper ocean internal wave field, eddy variability and the thermohaline stratification.

5. Results

At a minimum (assuming no additional information is received from the system), this ITP-V returned 5+ months of upper ocean temperature, salinity, velocity and turbulence data from the Makarov Basin, a region of the Arctic not well observed (particularly in winter). The CTD data recovered from the instrument, Figure 3, shows a hint of the warm Pacific Summer Water layer (local temperature maximum just below the surface mixed layer) and increasing mixed layer salinity with time/distance north (Figures 3, 4) as the system moved out of the Beaufort Gyre domain. As a contribution to the Stratified Ocean Dynamics of the Arctic DRI program (SODA), another ITP-V system is scheduled to be deployed in the Eurasian sector of the Arctic during the 2017 NABOS cruise. The data from ITP-V #92 will be valuable for comparison to this new data set, as well as to the MIZ and SODA observations from the Canada Basin, and to the wider collection of ITP temperature and salinity profiles within both basins.

Partially supported by the present grant, Cole (2016) reported on an analysis of lateral eddy stirring in the Arctic at the 2016 FAMOS (Forum for Arctic Modeling and Observational Synthesis) workshop. A decade of mooring observations from the BGOS program were used to estimate a representative depth profile of horizontal eddy diffusivity at 100 km horizontal scales for the Beaufort Gyre and Canada Basin. The

results show that eddy diffusivity decays with depth in the upper 300 m, and is spatially variable with elevated values near the basin boundaries. Estimates from Ice-Tethered Profilers with Velocity, including ITP-92, were similar even though they each derived from only one year of observations. These ITP-Vs showed signals of horizontal stirring on a range of scales from 1-100 km and over a broader region of the Arctic Ocean. These investigations into horizontal stirring and eddy diffusivity advance our understanding of key processes and parameters important to numerical modeling efforts.

The present grant also supported the ongoing analysis of data from the Marginal Ice Zone DRI program. Specifically, the project contributed to the submitted Cole et al. (2017a) manuscript discussing spatial and temporal changes in the sea ice-ocean coupling on subinertial time scales. Continuous observations in the Canada Basin from March through December 2014 were used to investigate spatial differences and temporal changes in under-ice roughness and momentum transfer as the ice cover evolved seasonally. Observations of wind, ice, and ocean velocity in combination with turbulent momentum flux measurements from four clusters of drifting instrument systems were analyzed, complemented by direct drill-hole measurements and IceBridge over flights in March, as well as remote sensing imagery about the instrument clusters. Observations captured near-complete seasonal melting of the ice cover. Spatially, estimated ice-ocean drag coefficients varied by a factor of three with rougher ice associated with smaller multi-year ice floe sizes embedded within the first-year-ice-multi-year-ice conglomerate. Temporal differences in the ice-ocean drag coefficient of 20-30% were observed prior to the mixed layer shoaling in summer and were associated with ice concentrations falling below 100%. In July and August, indirect indicators of ice-ocean drag and roughness suggested increased momentum transfer in low ice concentration conditions. The ice-ocean drag coefficient parameterization was found to be invalid in September with low ice concentrations and small ice floe sizes. The differing and temporally-variable nearby ice topography affected mixed layer currents, including the ocean's response to storm events. The kinetic energy budget of the ice showed that wind work and ocean work on the ice were the dominant terms controlling ice motion throughout the entire melt season. These seasonal changes in the air-ice-ocean system show that ice topography, ice concentration, and the shallow summer mixed layer all impact the ocean's response to forcing events. A second work on the MIZ internal wave observations (Cole et al., 2017b) is in preparation.

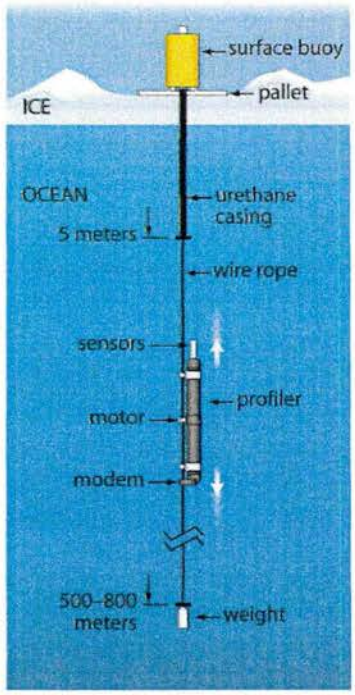
6. Impact for Science

The peer-reviewed scientific papers and meeting presentations based on the 2015-16 NABOS ITP-V data alongside those deriving from Marginal Ice Zone program observations constitute a major contribution to our understanding of the "new" Arctic Ocean with its much thinner and more mobile ice cover. Beyond the research contributions, the NABOS ITP-V program partially supported one new WHOI Assistant Scientist (Cole) who led several presentations and peer-reviewed papers based on these data.

7. Relationships to Other Programs

The 2015-16 NABOS ITP-V program has strong connections to the Marginal Ice Zone and Stratified Ocean Dynamics of the Arctic DRI activities. The data acquired under the present grant provide contrast to the MIZ observations (different ocean basin, different stratification, different season) and motivated the planned SODA ITP-V deployment during the 2017 NABOS expedition. As noted above, the present award also supported on-going scientific analysis of the MIZ observations.

8. Figures/Pictures



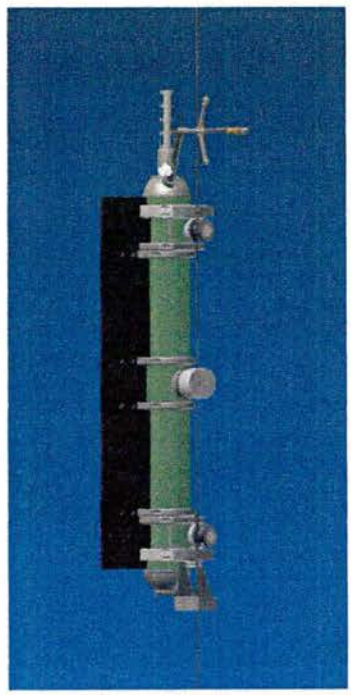


Figure 1. Schematic drawing of the generic Ice-Tethered Profiler instrument system (above left) and of the ITP-V version that includes an acoustic travel time current meter (above right). The photograph (right) shows one of the Marginal Ice Zone ITP-V instruments being deployed. Other MIZ instrumentation is visible in the background. Photo credit: John Kemp.

Figure 2. Drift track of the ITP-V instrument deployed during the 2015 NABOS expedition. The last received position from the instrument is marked with a white triangle.

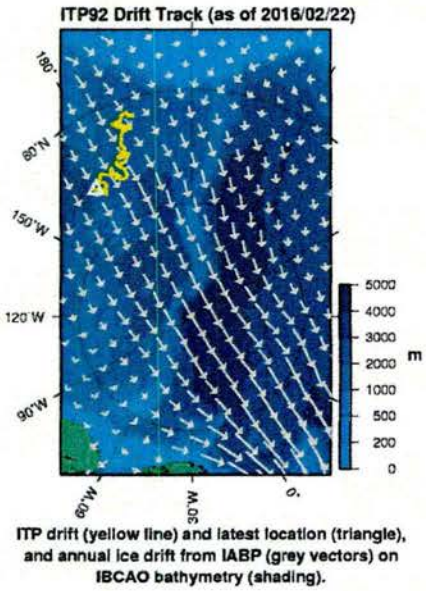


Figure 3. Depth-time contour plot of ocean temperature (top) and salinity (bottom) from the NABOS ITP-V system. Year day 255 in 2015 corresponds to September 12. In both cases, the upper 200 m and 0- to 750-m span are shown in separate panels.

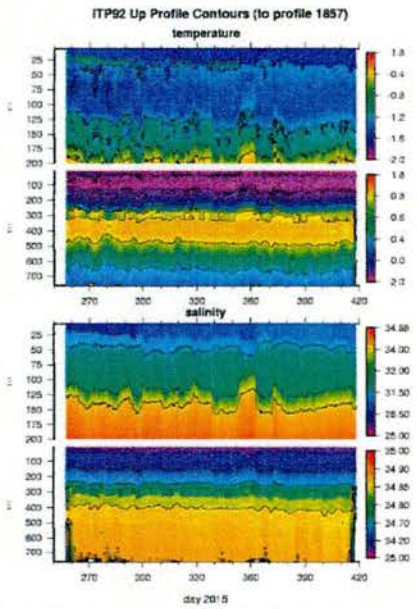
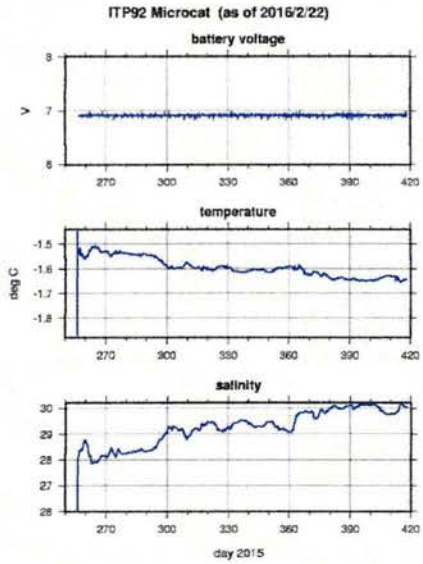


Figure 4. Time series of battery voltage and ocean temperature and salinity from the fixed-depth sensor mounted on the ITP-V underwater tether at 5-m depth just below the ice-ocean interface.



9. References

Cole, S.T., J. M. Toole, R. Lele, M.-L. Timmermans, S. G. Gallaher, T. P. Stanton, W. J. Shaw, B. Hwang, T. Maksym, J. P. Wilkinson, M. Ortiz, H. Graber, L. Rainville, A. A. Petty, S. Farrell, J. A. Richter-Menge and C. Haas, 2017a. Ice and ocean velocity in the Arctic marginal ice zone: Ice roughness and momentum transfer. *Elementa,* submitted.

Cole, S.T., 2016. Horizontal stirring and eddy diffusivity in the Arctic Ocean from observations. Presentation at the 2017 Forum for Arctic Modeling and Observational Synthesis (FAMOS) workshop, Woods Hole, MA November 1-4, 2016. Abstract available here: http://science.whoi.edu/users/aproshutinsky/2016_FAMOS_Meeting/FAMOS-ABSTRACTS.pdf

Cole, S.T., J.M. Toole, L. Rainville, and C. Lee, 2017b. Ice and ocean velocity in the Arctic marginal ice zone: Near-inertial motions and internal wave dynamics. In preparation.